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ORIGINAL ARTICLE

Cortical and trabecular bone at the radius and tibia in male and female adolescents with Down syndrome: a peripheral quantitative computed tomography (pQCT) study

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Abstract
Summary We aimed to describe the structure and strength of the tibia and radius of adolescents with Down syndrome. We observed that despite higher levels of volumetric bone mineral density in determined skeletal sites, they are at higher risk of developing osteoporotic fractures in the future due to their lower bone strength indexes.
Introduction The aims of the study were to describe the cortical and trabecular volumetric bone mineral density (vBMD), bone mineral content (BMC), area, and bone strength in adolescents with Down syndrome (DS) and to compare them with adolescents without disabilities.
Methods Thirty adolescents (11 girls) with DS and 28 without disabilities (10 girls) participated in the study. Peripheral quantitative computed tomography measurements were taken at proximal and distal sites of the tibia and radius. Values of total, trabecular, and cortical BMC; vBMD; and area were obtained of each scan. Cortical thickness and endosteal and periosteal circumferences were also measured, and different bone strength indexes were calculated. Student's *t* tests were applied between groups.
Results The DS group showed greater vBMD at distal radius, BMC at proximal radius, and total and cortical vBMD at proximal tibia. The non-DS group showed higher total and trabecular area at the distal radius and total, cortical, and trabecular BMC and area at distal tibia. Higher values of periosteal and endosteal circumference and bone strength were also found in non-DS group.
Conclusions From these results, it can be believed that even with higher vBMD in determined skeletal sites, adolescents with DS are at higher risk of suffering bone fractures due to an increased fragility by lower resistance to load bending or torsion.

Keywords Body composition · Bone geometry · Bone strength · Osteoporosis · vBMD

Introduction

Osteoporosis-related fractures constitute a major public health concern in the nowadays society [1, 2]. The fracture risk depends on several factors such as bone mineral density (BMD), bone geometry, or bone strength [3, 4]. Several studies showed an increased prevalence of osteopenia and osteoporosis in persons with intellectual disability, identifying Down syndrome (DS) as one of the main contributors for low BMD in those persons [5–7]. The increment in the lifespan of persons with DS occurred over the last decades allows to believe that osteoporotic diseases are likely to appear in a relatively close future in this population [8, 9].

Numerous studies performed with dual energy X-ray absorptiometry (DXA) showed lower levels of bone mass in persons with DS compared with their counterparts without DS at all ages [10–17]. Despite of this, the body composition of adolescents with DS has not been studied in detail, and several issues are still pending to be considered [18]. DXA use a two-dimensional image of the bone (often expressed as "areal" BMD; in grams per square centimeter) which does

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not provide information about volumetric BMD (vBMD) and does not differentiate cortical and trabecular bone. As small stature and stunted growth are among the most common clinical characteristic of persons with DS [19, 20] and it is known that DXA tends to underestimate BMD in those who are smaller than normal size for chronological age (even when adjusting values for height) [21], it is possible to hypothesize that DXA is not the best method for measuring BMD in persons with DS. Even with this, a couple of studies calculated an estimation of vBMD from data obtained with DXA, based on simple geometric cylindrical models. These studies found differences in vBMD at lumbar spine in adults with DS, but not in adolescents at lumbar spine or femoral neck compared with those without DS [12, 15]. However, these assumptions have not been yet confirmed using other techniques of bone assessment which actually measure vBMD.

As it has been observed, osteoporosis is highly related with BMD; however, strength indexes and, therefore, fracture risk have a high relationship with structural aspects of the bone such as cortical thickness and bone cross-sectional area, among others. Peripheral quantitative computed tomography (pQCT) is an alternative bone densitometry technique that allows evaluating separately the cortical and trabecular bone. This technique is also able to assess actual vBMD at peripheral sites as well as estimate geometric properties of bone which are related to bone strength, going beyond the scope of current DXA determinations. The low dose of radiation produced by pQCT (slightly lower than by DXA) makes this method suitable for using with pediatric populations.

Though many studies have detected lower areal BMD in persons with DS, few have examined other measurements of bone strength such as actual vBMD, and no one of them has actually measured those values, only estimations were used. Therefore, the main aims of this study were to assess the cortical and trabecular vBMD, bone mineral content (BMC), area, and bone strength at proximal and distal sites of tibia and radius in adolescents with DS and to compare these results with healthy counterparts without disabilities.

Methods

Participants

A total sample of 30 adolescents (11 females, 19 males) with DS living at home, between 11.5 and 20 years old, were recruited from different special schools and institutions within the region of Aragon, in Spain. Another individually age-matched sample of 28 adolescents (10 females, 18 males) without DS was also recruited from regular schools in this region (non-DS group). All the adolescents without DS were healthy, without known illness, and had been medication-free for at least 6 months before the tests. Both parents and children were informed about the aims and procedures of the study, as well as the possible risks and benefits, and then, a letter of written informed consent was obtained from all the included participants and/or their parents or guardians. The study was performed in accordance with the Helsinki Declaration of 1961 (revised in Edinburgh, 2000) and was approved by the Research Ethics Committee of the Government of Aragon (CEICA, Spain).

Anthropometric

All participants were measured with a stadiometer without shoes and the minimum clothes to the nearest 0.1 cm (SECA 225, SECA, Hamburg, Germany) and weighted to the nearest 0.1 kg (SECA 861, SECA, Hamburg, Germany). Body mass index (BMI) was calculated as weight (in kilograms) divided by height (in square meters).

Pubertal status assessment

Pubertal development was determined by direct observation according with the five stages proposed by Tanner and Whitehouse [22].

Bone assessments by peripheral quantitative computed tomography

pQCT measurements were taken at two sites of the radius and three sites of the tibia using a Stratec XCT-2000 L pQCT scanner (Stratec Medizintechnik, Pforzheim, Germany). The device is a translate-rotate, small bore computed tomography scanner that acquires a trans-axial image. The X-ray source is a narrow fan beam with an effective width of 2.3 mm and a total radiation dose associated lower than 2 μSv. Images were acquired with an in-plane voxel dimension of 0.2 mm (0.008 mm^3). To ensure machine stability, the pQCT device was assessed daily based on a quality control phantom (Stratec Medizintechnik, Pforzheim, Germany), which includes soft tissue equivalent material. The coefficient of variation between measurements is lower than 1 % for that phantom.

Scanning procedure

For each participant, the non-dominant upper and lower limbs were selected for measurements. Participants were seated in a stationary chair, adjusted to the appropriate height. For the radius scans, the length of the bone from humeroradial joint cleft to the styloid process was measured. For the tibia scans, the length of the bone from the distal end of the medial malleolus to the medial knee joint cleft was

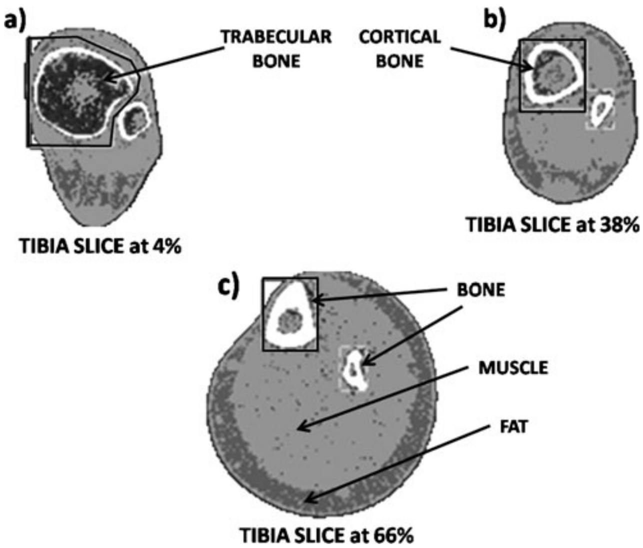

Fig. 1 Different scan sites for the lower limb assessment

measured. A radial or tibial adjustable fasten was used to hold the limb and to limit motion during the scans. Every limb was centered in the imagining field. The scanner was positioned on the distal radius or distal tibia, and a coronal computed radiograph (scout view) was performed to manually locate a reference line on the distal end of either the radius or the tibia. The measurement sites were located proximal to this reference line by a distance corresponding to 4 % (distal radius) and 66 % (diaphyseal radius) of the forearm length, and 4 % (distal tibia) and 38 % (diaphyseal tibia) of the tibia length, as previously described [23]. For muscle, subcutaneous fat, and bone cross-sectional area, the measurement site was at 66 % of the length of the tibia, where the largest calf diameter is typically located. See Fig. 1a–c for the different scan sites. Each scan required approximately 90 s, with some variability depending upon the cross-sectional size of the upper or lower limb.

Measurement parameters

Version 6.20 of the manufacturer's software was used to analyze and select thresholds. Several parameters were determined at the described bone sites: (1) BMC (in grams per 1 cm slide): total BMC (TOT_BMC), trabecular BMC (TRAB_BMC), and cortical BMC (CRT_BMC); (2) cross-sectional area of bone (in square millimeters): total cross-sectional area (TOT_A), trabecular area (TRAB_A), and cortical area (CRT_A); and (3) vBMD (in milligrams per cubic centimeter): total vBMD (TOT_vBMD), trabecular vBMD (TRAB_vBMD), and cortical vBMD (CRT_vBMD). Also cortical thickness (CRT_THK, in millimeters), endosteal circumference (ENDO_CIR, in millimeters), and periosteal circumference (PERI_CIR, in millimeters) were measured at 66 % of the tibia. A threshold of 280 mg/cm^3 was used to detect periosteal surface of the bone and to distinguish trabecular from cortical bone. TRAB_vBMD and TRAB_BMC were determined from a central area covering

Table 1 Descriptive characteristics of the sample

	Group			Boys		Girls	
	Group	*n*	Mean±SD	*n*	Mean±SD	*n*	Mean±SD
Age (years)	DS	30	15.52±2.59	19	16.27±2.39	11	14.25±2.50
	Non-DS	28	14.94±2.23	18	15.17±2.00	10	14.52±2.67
Weight (kg)	DS	30	52.39±10.94	19	53.94±8.33	11	49.76±14.50
	Non-DS	28	56.20±12.57	18	58.01±13.67	10	53.32±10.60
Height (cm)	DS	30	150.91*±9.43	19	153.75*±8.85	11	146.09*±8.76
	Non-DS	28	162.00±12.35	18	165.10±11.61	10	157.04±12.43
Tanner stage (I, II, III, IV, V)	DS	30	1/2/6/6/15	19	0/0/3/6/10	11	1/2/3/0/5
	Non-DS	28	1/3/7/0/17	18	1/2/4/0/11	10	0/1/3/0/6
BMI (kg/m^2)	DS	30	22.95±4.34	19	22.79±2.69	11	23.24±6.44
	Non-DS	28	21.14±2.61	18	20.94±2.87	10	21.45±2.23
Tibia length (mm)	DS	30	323.85*±27.21	19	330.63*±26.26	11	313.00*±26.37
	Non-DS	28	361.79±31.48	18	372.78±31.31	10	342.00±21.11
Radius length (mm)	DS	30	223.33*±19.06	19	231.76*±18.20	11	209.00*±9.94
	Non-DS	28	247.32±22.26	18	255.83±22.64	10	232.00±10.59

DS group with Down syndrome, *Non-DS* group without Down syndrome, *BMI* body mass index, *SD* standard deviation

*$p<0.05$ between DS and non-DS

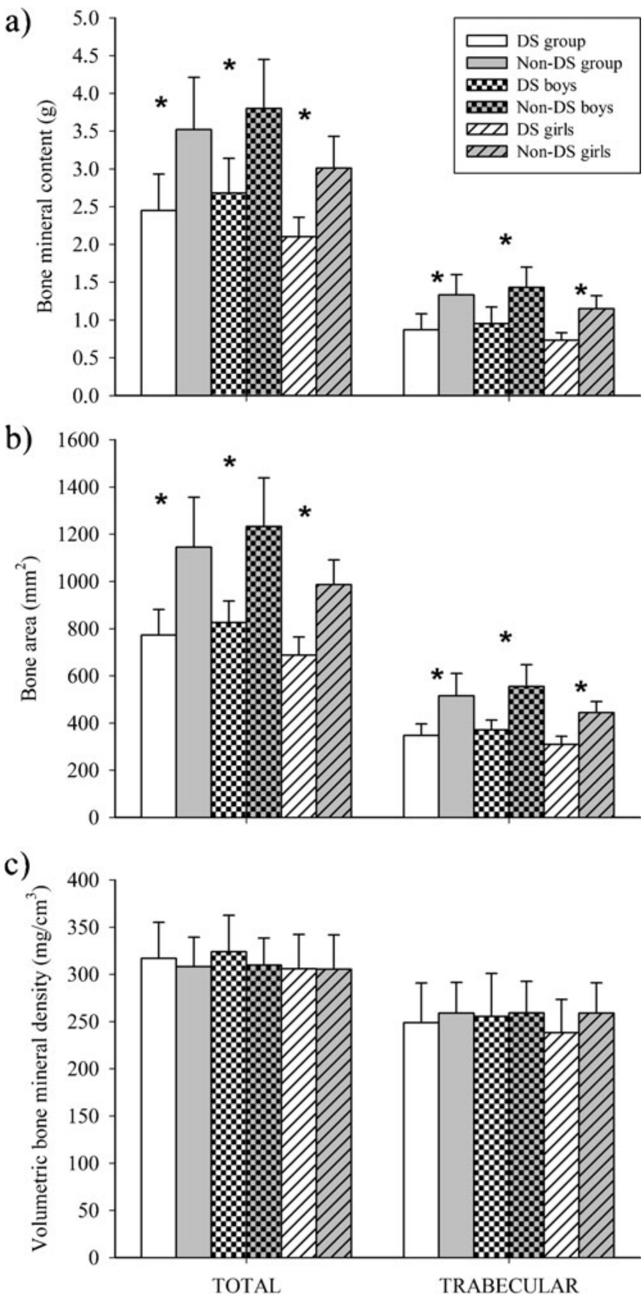

Fig. 2 Bone variables at the 4 % of the length of the tibia. *DS* Down syndrome; *$p<0.05$ between DS and non-DS

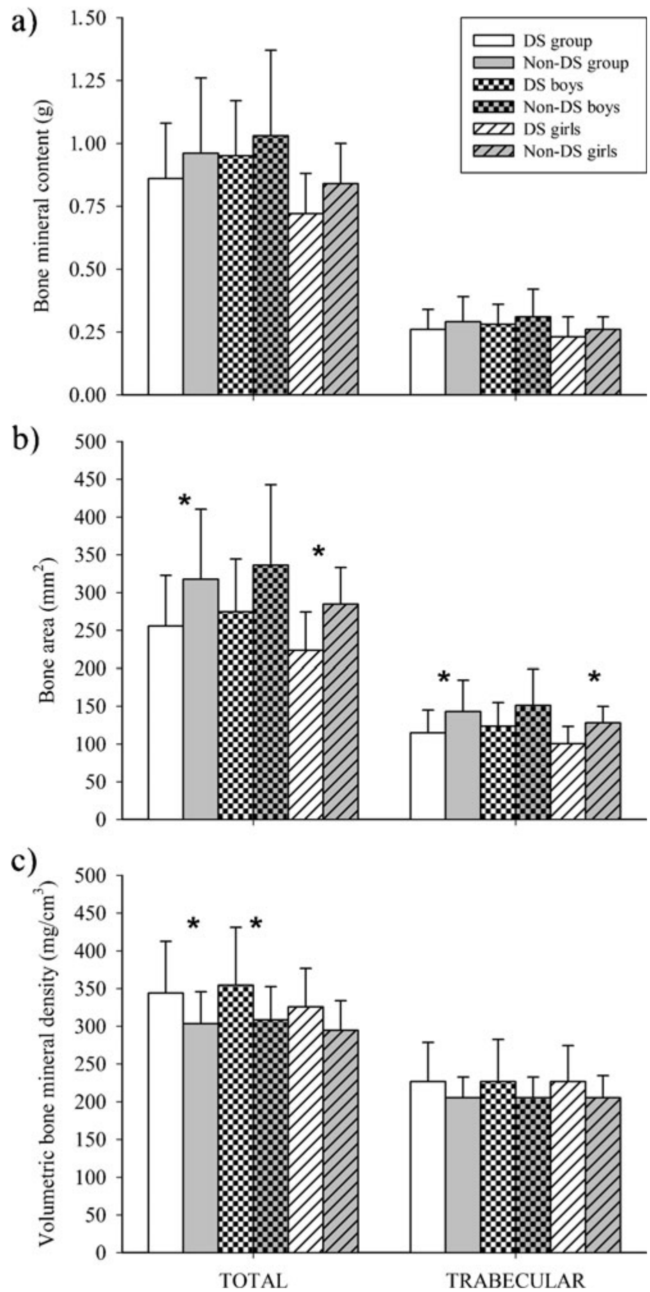

Fig. 3 Bone variables at the 4 % of the length of the radius. *DS* Down syndrome; *$p<0.05$ between DS and non-DS

45 % of the total bone cross-sectional area. In the cortical compartment, many voxels are only partially occupied by cortical bone; however, at a threshold of 710 mg/cm^3, the number of such voxels that are included in the analysis is equivalent to the number excluded. Bone strength was established with respect to torsion (polar stress strain index or SSI, in cubic millimeters), and bending (fracture load, in Newton) both with respect to the *X*- or *Y*-axis; also the bone strength index (BSI, in square milligrams per quartic millimeter) was calculated as previously described [24–26]:

$$BSI = TOT\_vBMD^2 \times TOT\_A$$
$$SSI = \sum \left(\mathrm{d_x}^2 \times \mathrm{A}_v \times \mathrm{D}_v / PCoD \right) / \mathrm{d}_{\mathrm{x}max}$$

where *d* is the distance from a cortical voxel to the *x*-axis, A_v is the area of the voxel, D_v is the density of the voxel, and PCoD is the estimated physiological "maximal" cortical bone density (1,200 mg/cm^3).

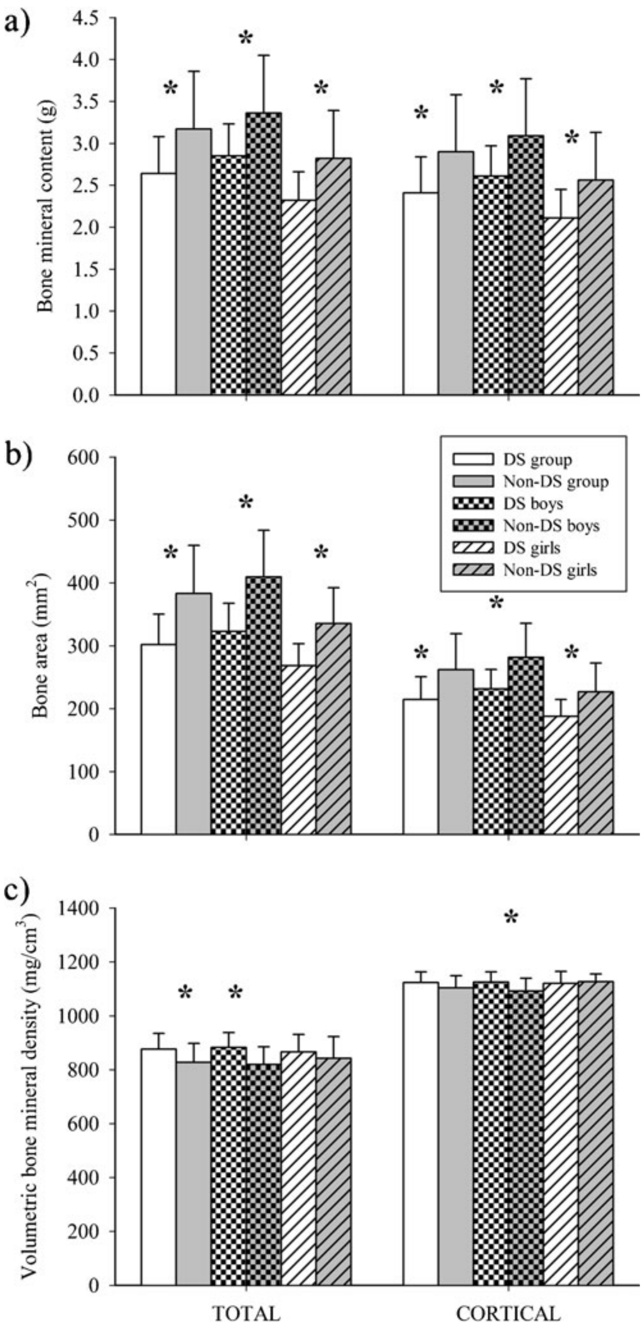

Fig. 4 Bone variables at the 38 % of the length of the tibia. *DS* Down syndrome; *$p<0.05$ between DS and non-DS

For the analysis of muscle cross-sectional area, the region of interest was defined to include the entire matrix (skin, subcutaneous tissue, muscle, and bone). A threshold set at 40 mg/cm^3 was used within this region, to determine the total area of the muscle, and the total bone was assessed with a threshold of 710 mg/cm^3. The total area of skin and subcutaneous fat was identified using a threshold of 100 mg/cm^3. Subsequently, the total bone area and total areas of skin and subcutaneous fat were deducted from the region of interest to yield the total muscle area which was found between the thresholds of 40 and 710 mg/cm^3.

Statistics

The Statistical Package for the Social Sciences (version 15.0 for Windows) was used to conduct statistical analyses. Descriptive statistics including number of participants (n), mean, and standard deviation values were calculated for each variable. The normality in the distribution of the variables was established by using Kolmogorov–Smirnov tests. To compare DS and non-DS groups, two-sided Student's t tests were performed. For avoiding possible influences of height in bone parameters, all the analyses were repeated using bone length as a covariate (analysis of covariance). Every analysis was executed with all the participants within a group as a whole and separately by gender. Effect size statistics using Cohen's d (G*Power Version 3.1.2) were calculated [27]. Taking into account the cutoff established by Cohen, the effect size can be small (under 0.2), medium (over 0.2 and under 0.5), or large (over 0.8). Statistical significance was set at $p<0.05$.

Results

Participant characteristics

Table 1 shows descriptive characteristics of participants by condition and gender. There were no differences between groups for age, weight, Tanner stage distribution, or BMI, but DS boys and girls resulted significantly smaller than boys and girls without DS, respectively (both $p<0.05$). Also DS adolescents showed shorter tibia and radius than those without DS (all $p<0.05$).

Distal radius and tibia

Scans with a high level of motion artifact (the software assesses each analysis as good, invalid, or aborted) were excluded, and sample size could not be the same for each variable. As explained in the operator's manual provided by the manufacturer, the factors which determine the artifacts are positioning of patient, selection of the scan positions, movements of the subject, and/or interference with other devices.

Figure 2a–c displays the pQCT variables measured at the 4 % distal tibia. The DS adolescents as a group and also separated by gender showed lower mean values of TOT_BMC, TOT_A, TRB_BMC, and TRB_A than their counterparts without DS (all $p<0.05$; Cohen's d ranged from

Table 2 Geometric variables and strength indexes at the 38 % of the length of the tibia

	Group			Boys		Girls	
	Group	*n*	Mean±SD	*n*	Mean±SD	*n*	Mean±SD
CRT_THK (mm)	DS	26	4.53±0.53	16	4.75±0.47	10	4.18±0.43
	Non-DS	28	4.83±0.73	18	5.02±0.64	10	4.49±0.79
PERI_CIR (mm)	DS	26	61.40*±4.99	16	63.56*±4.39	10	57.96*±3.96
	Non-DS	28	69.05±6.91	18	71.44±6.59	10	64.74±5.39
ENDO_CIR (mm)	DS	26	32.93*±3.65	16	33.70*±3.87	10	31.70*±3.04
	Non-DS	28	38.68±5.04	18	39.88±4.23	10	36.52±5.87
FRC_LOAD_X (N)	DS	26	2,253.16*±610.21	16	2,543.14*±539.29	10	1,789.19*±401.15
	Non-DS	28	3,215.14±966.90	18	3,509.75±914.86	10	2,684.86±858.90
FRC_LOAD_Y (N)	DS	26	1,886.78*±395.65	16	2,052.78*±327.45	10	1,621.17*±358.82
	Non-DS	28	2,734.93±841.45	18	3,045.99±808.21	10	2,175.01±590.27
SSIX (mm^3)	DS	26	532.30*±133.72	16	706.43*±149.80	10	497.00*±111.43
	Non-DS	28	787.99±269.79	18	974.93±254.13	10	745.79±238.58
SSIY (mm^3)	DS	26	524.11*±109.9	16	570.22*±90.96	10	450.32*±99.67
	Non-DS	28	759.7±233.73	18	846.11±224.50	10	604.17±163.96
SSI_POL (mm^3)	DS	26	625.88*±169.5	16	706.43*±149.80	10	497.00*±111.43
	Non-DS	28	893.09±268.58	18	974.93±254.13	10	745.79±238.58
BSI (mg^2/mm^4)	DS	26	2,325.16±457.43	16	2,517.7±396.41	10	2,017.09±384.67
	Non-DS	28	2,641.08±707	18	2,776.74±695.1	10	2,396.88±695.6

DS group with Down syndrome, *Non-DS* group without Down syndrome, *SD* standard deviation, *CRT_THK* cortical thickness, *ENDO* endosteal circumference, *PERI* periosteal circumference, *FRC_LOAD* fracture load (axes *X* and *Y*), *SSI* strength strain index (axes *X* and *Y*, and polar), *BSI* bone strength index

*$p<0.05$ between DS and non-DS

1.8 to 3.3). Figure 3a–c summarizes the pQCT variables measured at 4 % distal radius in DS and non-DS adolescents. The DS adolescents as a group and the DS boys separately showed higher values of TOT_vBMD than the non-DS group and non-DS boys (both $p<0.05$; Cohen's d 0.7 and 0.73, respectively). The DS adolescents as a group and the DS girls separately demonstrated lower TOT_A and TRB_A than their respective non-DS counterparts (both $p<0.05$; Cohen's d 0.76 for group TOT_A and over 0.8 for the rest of variables).

Diaphyseal radius and tibia

In Fig. 4a–c is displayed the bone variables and in Table 2 geometric variables and strength indexes at the 38 % diaphyseal site of the tibia. The DS group as a whole and also separately by gender showed significantly lower values for TOT_BMC, TOT_A, CRT_BMC, CRT_A, PERI_CIR, ENDO_CIR, SSI (in both X- and Y-axis, and polar), and fracture load (in both X- and Y-axis) (all $p<0.05$; Cohen's d ranged from 0.86 to 1.42). The DS group and also the boys with DS separately demonstrated higher TOT_vBMD than the non-DS group and boys, respectively; the boys with DS also showed higher CRT_vBMD than the non-DS boys (all $p<0.05$; Cohen's d 0.75, 0.79, and 1.04, respectively). Figure 5a–c shows data of bone and Table 3 geometry and strength at the 66 % of the radius. At this site, the DS adolescents as a whole and also boys with DS showed significantly higher values for TOT_BMC than their respective non-DS counterparts (both $p<0.05$; Cohen's d 0.57 and 0.69, respectively).

Bone, subcutaneous fat, and bone cross-sectional area

Table 4 summarizes the results for muscle, fat, and bone area at the 66 % site of the tibia. The DS group and the girls with DS showed lower levels of muscle area than the non-DS group and girls, respectively; also lower levels of bone cross-sectional area were observed in the DS group as a whole and separately by genders (all $p<0.05$; Cohen's d for the whole group muscle area 0.61 and over 0.8 for the rest of variables). Further adjustment by bone length did not substantially change the results (data not shown).

Discussion

In this cross-sectional study, we investigated the differences between trabecular microstructure and cortical bone size, among other parameters, between adolescents with and

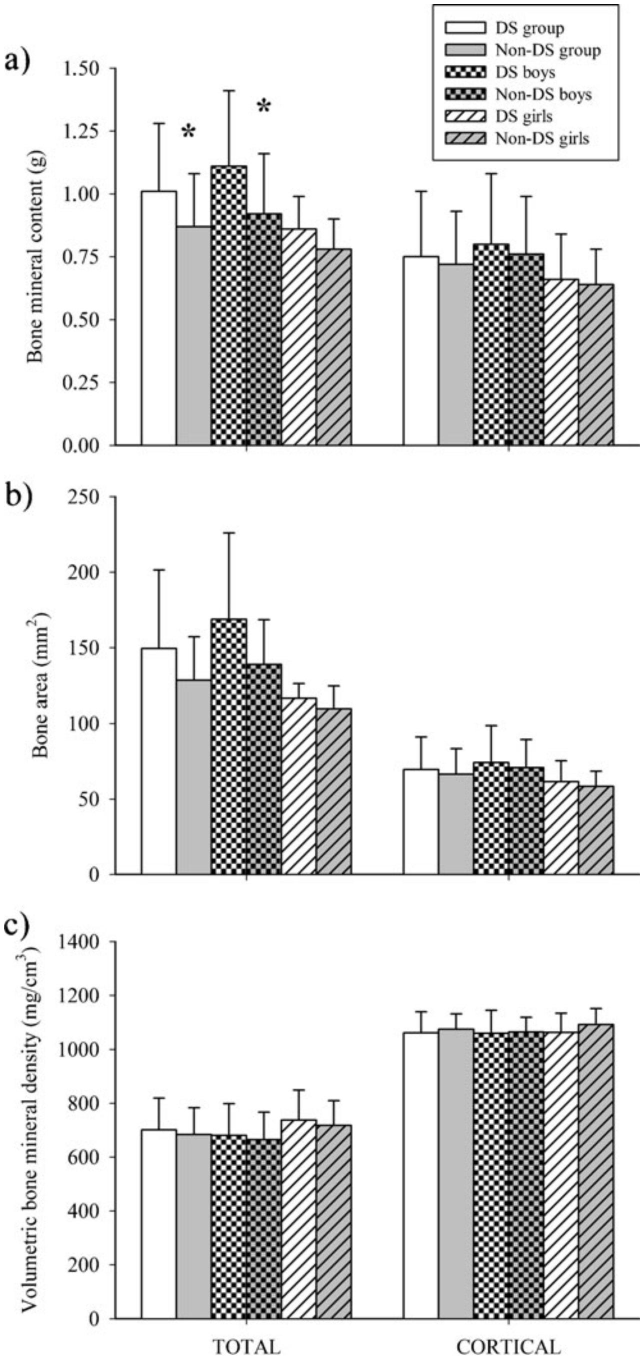

Fig. 5 Bone variables and strength indexes at the 66 % of the length of the radius. *DS* Down syndrome; **p*<0.05 between DS and non-D

without DS, using pQCT. To the best of our knowledge, this is the first study examining these variables on this determined population. The main finding of this study is that despite higher vBMD was found in some regions of the tibia and radius in adolescents with DS, their lower levels of BMC and area in total, cortical, and trabecular bone and their bone geometry lead them to an increased fracture risk.

Differences between adolescents with and without DS

The assurance of previous studies demonstrating low levels of areal BMD at whole body and critical regions measured with DXA in persons with DS [11, 12, 14–16] made us to suppose that lower values measured with pQCT could also be found in this population. Conversely to that, our results indicated higher values of total vBMD and BMC at the radius and total and cortical vBMD at the tibia in adolescents with DS compared with those without. Taking into account the previous results, it could be assumed that adolescents with DS are not at higher risk of bone fractures than their non-DS peers. However, several factors account for bone strength and therefore for the risk of suffering a fracture; those factors include BMC, area, and geometry among others. In fact, Kontulainen et al. found that greater than 80 % of the variance in failure moment at diaphyseal site was predicted by total and cortical are and content, geometry, and SSI [26]. In this study, lower levels of total, trabecular, and cortical content and area and smaller periosteal and endosteal circumferences were observed in adolescents with DS compared with those without, leading them to a diminished fracture load and SSI.

Despite no studies to the date were carried out pQCT measurements in a population with DS, some of the previous studies calculated an estimate of vBMD from the data obtained with DXA based on geometric cylindrical models [12, 15]. Baptista et al. [15] found lower vBMD at lumbar spine in adults (over 20 years), but not in adolescents with DS compared with their counterparts without DS, and González-Agüero et al. [12] confirmed those results in another sample of adolescents with DS and also found no differences at the femoral neck. Both studies were performed with DXA and examined different body regions than ours; nevertheless, authors believe that our results reinforce their postulation that adolescents with DS have not a deficit in vBMD compared with their counterparts without DS and that differences start to appear later in life.

For possible sex differentiations in bone development, we explored differences between DS and non-DS groups separately by gender. In general, the results observed with all participants within a group as a whole did not differ from those observed separately, with the exception that girls with DS did not show higher values than non-DS girls in any variable and that boys with DS did not show lower total and trabecular area at the radius neither cross-sectional muscle area than non-DS boys. The reason for these gender differences could be that young females with DS are poorer at acquiring bone mass than young males with DS, as it was hypothesized in a previous study [12].

Some limitations to this study should be recognized. Despite the number of participants was comparable to other studies performed with pQCT in populations with special

Table 3 Geometric variables and strength indexes at the 66 % of the length of the radius

	Group			Boys		Girls	
	Group	*n*	Mean±SD	*n*	Mean±SD	*n*	Mean±SD
CRT_THK (mm)	DS	26	2.00±0.50	16	2.04±0.49	10	1.94±0.52
	Non-DS	28	1.96±0.41	18	2.00±0.45	10	1.89±0.34
PERI_CIR (mm)	DS	27	42.76±6.97	17	45.45±7.54	10	38.19±1.63
	Non-DS	28	39.92±4.39	18	41.52±4.44	10	37.05±2.54
ENDO_CIR (mm)	DS	27	30.54±8.52	17	33.21±9.45	10	25.99±3.79
	Non-DS	28	27.60±4.22	18	28.94±4.08	10	25.18±3.44
FRC_LDX (N)	DS	27	491.04±225.28	17	578.59±234.67	10	342.21±98.11
	Non-DS	28	469.39±167.33	18	518.89±183.31	10	380.27±82.47
FRC_LDY (N)	DS	27	564.45±217.04	17	651.98±220.34	10	415.66±103.47
	Non-DS	28	520.29±201.47	18	583.13±214.78	10	407.18±111.91
SSIX (mm^3)	DS	26	136.40±62.58	17	160.72±65.19	10	95.06±27.25
	Non-DS	28	130.39±46.48	18	144.14±50.92	10	105.63±22.91
SSIY (mm^3)	DS	26	156.79±60.29	17	181.11±61.20	10	115.46±28.74
	Non-DS	28	144.53±55.96	18	161.98±59.66	10	113.11±31.09
SSI_POL (mm^3)	DS	26	241.03±102.08	17	276.05±108.48	10	181.51±54.11
	Non-DS	28	242.94±88.92	18	270.60±93.80	10	193.16±53.06
BSI (mg^2/mm^4)	DS	26	714.00±232.29	17	757.09±254.53	10	640.75±176.74
	Non-DS	28	605.40±195.57	18	626.55±221.21	10	567.32±140.74

DS group with Down syndrome, *Non-DS* group without Down syndrome, *SD* standard deviation, *CRT_THK* cortical thickness, *ENDO* endosteal circumference, *PERI_CIR* periosteal circumference, *FRC_LOAD* fracture load (axes *X* and *Y*), *SSI* strength strain index (axes *X* and *Y*, and polar), *BSI* bone strength index

characteristics [23, 28–31], the specificity of the condition and the limited age range became complicated to increase the sample size. Regarding this number of participants, the large effect sizes observed in the vast majority of the differences indicate a substantial biological magnitude of the results. In addition, this study has been carried out with healthy non-overweight Caucasian adolescents with Down syndrome; therefore, the results only apply to this population. Further studies are needed in order to confirm these findings in other populations with Down syndrome such as overweight/obese or adult persons. As strengths, our study was the first in assessing actual vBMD, as well as other important structural architectural bone properties and indexes in a population of persons with DS, including both genders, and was performed in a crucial age for acquiring bone mass. A longitudinal study could help to corroborate the hypothesis that the low vBMD in adult populations with DS is due to a lower acquisition during the most important years of accumulation.

Some research has been made aiming to improve the body composition of adolescents with DS, finding reductions in the percentage of fat mass and increments in the lean and bone

Table 4 Cross-sectional muscle, subcutaneous fat, and bone are at 66 % of the length of the tibia

	Group			Boys		Girls	
	Group	*n*	Mean±SD	*n*	Mean±SD	*n*	Mean±SD
Area (mm^2)							
Total muscle	DS	24	5,544.55*±1,208.93	15	6,089.10±972.51	9	4,636.97*±1,031.54
	Non-DS	28	6,342.96±1,362.37	18	6,735.17±1,396.20	10	5,637.00±1,012.23
Total fat	DS	26	2,914.80±1,940.51	16	2,818.22±2,117.13	10	3,069.33±1,716.52
	Non-DS	28	2,510.56±901.00	18	2,203.51±856.13	10	3,063.25±723.16
Total bone	DS	26	301.95*±48.49	16	322.89*±44.44	10	268.45*±34.84
	Non-DS	28	383.05±76.46	18	409.43±74.34	10	335.58±56.58

DS group with Down syndrome, *Non-DS* group without Down syndrome, *SD* standard deviation

**p*<0.05 between DS and non-DS

masses over a relatively short period of time [32–34]. Therefore, interventional studies using specifically designed training programs could help adolescents with DS to enhance some parameters of trabecular and/or cortical BMC and area, and bone strength.

In conclusion, the current study provides evidence that adolescents with DS have a tendency toward lower cortical and trabecular BMC and area, but not vBMD at several sites of tibia and radius compared with age-matched adolescents without DS. This establishes that our population study is at higher risk of bone fractures due to decreased bone strength regarding bending and torsion. Longitudinal studies aiming to identify critical periods of bone development may help to corroborate the hypothesis that lower vBMD appears in persons with DS after the age of 20.

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Conflicts of interest None.

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